

# Scaling from field to region for wind erosion prediction using the Wind Erosion Prediction System and geographical information systems

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**Abstract:** The Wind Erosion Prediction System (WEPS) simulates soil erosion and dust emissions from agricultural soils. Due to the severe risk of wind erosion in Adams County, Washington, WEPS and ArcGIS were used to simulate soil loss and particulate matter  $\leq 10 \mu\text{m}$  in diameter (PM10) emissions. On a countywide basis, WEPS predicted an annual soil loss of  $14,250 \text{ kg ha}^{-1}$  ( $6.4 \text{ tons ac}^{-1}$ ) and PM10 loss of  $390 \text{ kg ha}^{-1}$  ( $0.2 \text{ tons ac}^{-1}$ ) from fields in summer fallow. Soil loss from fields in summer fallow was highest in west-central and south-central Adams County; thus, soil conservation strategies aimed at reducing wind erosion may be most effective in these parts of the county. The USDA Soil Survey Geographic database classifies Adams County into six wind erodibility groups (WEG) with soil loss increasing in severity from WEG1 to WEG6. Our assessment of soil loss using WEPS indicated that soil loss was highest for soils designated as WEG1 and lowest for soils designated as WEG2 whereas PM10 emissions were highest for WEG4 and lowest for WEG2. This study demonstrated that wind erosion assessments and inventories can be made by scaling from field to region using WEPS and a geographic information system.

**Key words:** air quality—geographical information system (GIS)—particulate matter—Soil Survey Geographic database—wind erosion—wind erodibility groups—wind erodibility index—Wind Erosion Prediction System

**Soil wind erosion and windblown dust have long been a major concern within the Columbia Plateau of the Pacific Northwest.** Wind removes the fertile topsoil, thereby degrading soil quality and reducing agricultural sustainability. Sharratt et al. (2006), for example, estimated a loss of topsoil of  $2,320 \text{ kg ha}^{-1}$  ( $1.04 \text{ tons ac}^{-1}$ ) from a field maintained in summer fallow during a single dust storm near Washtucna, Washington in 2003. Off-site transport of wind blown soil can severely affect crop emergence and damage young plants, which often requires reseeding fields (Papendick 2004). Windblown dust generated from farmland also poses a hazard to motorists. Poor visibility caused by windblown dust has been the cause of numerous fatalities, accidents, and road closures within the Columbia Plateau. In September 1999, for example, poor visibility caused by blowing

dust resulted in eight fatalities along Interstate 84 near Pendleton, Oregon (Hudson and Cary 1999). Likewise, in March 2005, poor visibility from blowing dust resulted in closure of Interstate 90 after a four-vehicle accident occurred near Moses Lake, Washington (Wheat and Feeney 2005). Windblown dust can also impair human health as dust particles enter the respiratory system, thus the US Environmental Protection Agency (USEPA) has set air quality standards for dust particle concentrations in the atmosphere. Saxton (1995) reported that wind erosion was a major cause of non compliance of the USEPA National Ambient Air Quality Standard for particulate matter  $\leq 10 \mu\text{m}$  in diameter (PM10) within the Columbia Plateau.

Dryland agriculture is practiced on about  $3.3 \times 10^6 \text{ ha}$  ( $8.2 \times 10^6 \text{ ac}$ ) in the inland Pacific Northwest; half of this hectareage is

in fallow on an annual basis (Schillinger et al. 2004a). Land is maintained in summer fallow for over 12 consecutive months to conserve soil moisture, during which time the soil is vulnerable to wind erosion. Land in summer fallow is often blamed as one of the major sources of dust and PM10 in this region (Saxton 1995). However, no assessment has been made of potential soil loss and PM10 emission from fields in summer fallow at regional scales within Columbia Plateau despite the availability of new wind erosion prediction technologies capable of simulating soil loss and PM10 emissions. Regional assessments could not only illuminate areas most susceptible to wind erosion and PM10 emissions, but could also target areas for implementing alternative control strategies and USDA conservation programs.

Field monitoring to obtain regional inventories of wind-blown soil loss and PM10 emission would require a large investment of human resources and equipment. As an alternative, models can be used to conduct regional assessments of soil loss and PM10 emission. Wind erosion prediction technologies have progressively developed over the last several decades. The Wind Erosion Equation (WEQ) was developed in the 1960s for predicting annual soil erosion across a uniform field (Woodruff and Siddoway 1965). In the 1990s the Revised Wind Erosion Equation (RWEQ) was developed to predict wind erosion on an event or daily basis (Fryrear et al. 1998). Although still under development, the Wind Erosion Prediction System (WEPS) is being developed to simulate creep, saltation, and suspension processes under a wide range of environmental conditions and management practices (Hagen 1991).

The WEPS was designed to replace WEQ for overcoming the limitations of highly empirical equations (Hagen 1991). WEPS is a process-based, daily time step model that has the ability to simulate both soil erosion and PM10 emissions from two-dimensional agricultural fields in response to variations in weather, soil, and land management practices. The largest contrast between these two

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technologies is that WEPS simulates a wide range of processes to describe real-time field surface conditions whereas WEQ depends on user input to correctly document field surface conditions. A detailed comparison between WEQ and WEPS can be found in the WEPS user manual (Hagen et al. 1995).

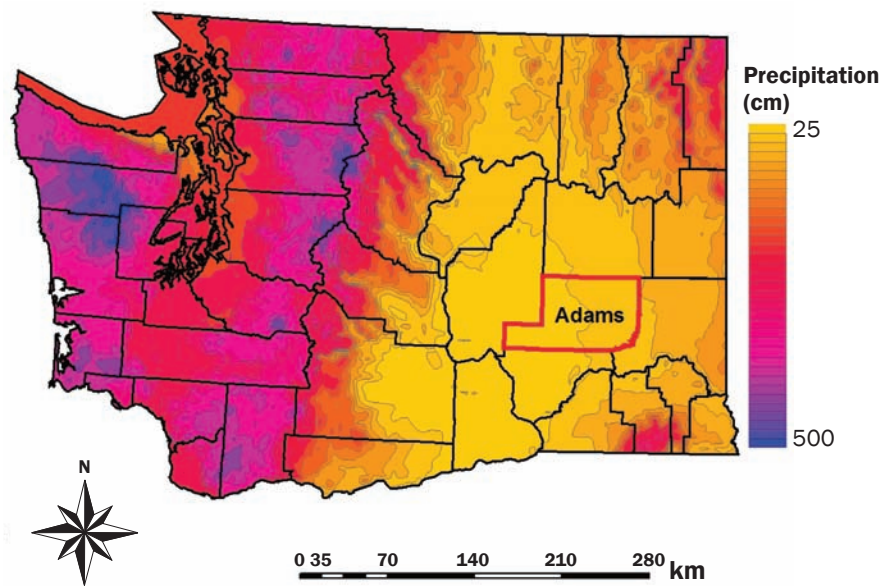
WEPS was used by Coen et al. (2004) to predict the wind erosion risk within Alberta, Canada. Unfortunately, no similar published work has been found for the United States. Previous assessments of soil erosion and PM10 emission within the Columbia Plateau region of eastern Washington was based solely on the mass fraction of surface soil aggregates less than 0.84 mm (0.03 in) in diameter (Chepil 1941), statistical relationships between measured total soil mass flux using a portable wind tunnel and aggregate size distribution (Chandler and Saxton 2001; Chandler et al. 2004), and semi-empirical equations describing horizontal and vertical dust flux (Saxton et al. 2000; Sundram et al. 2004). All of these studies lacked the ability to deal with the spatial and temporal variability in soils and cropping practices across a region.

WEPS is a field-scale model that was designed for field application. As such, methodologies are required to scale up from field to region. A geographical information system (GIS) has been demonstrated to be an effective tool to estimate soil wind erosion and PM10 emission at regional scales (Chandler et al. 2004; Coen et al. 2004; Pulugurtha and James 2006; Zobeck et al. 2000). Accurate estimation of wind-induced soil loss and PM10 emission using WEPS at a regional scale requires spatially distributed input data of site-specific soil properties and surface characteristics. The USDA Soil Survey Geographic Database (SSURGO) provides spatially distributed soils data useful for WEPS applications (Feng and Sharratt 2005). While WEPS is a process-based model, its applicability in simulating regional soil and PM10 loss can only be verified through field testing. Field validation of WEPS has been carried out, and the results indicate that the model can be used with acceptable resolution within the Columbia Plateau (Feng and Sharratt 2006; Hagen 2004).

The objectives of this study were to demonstrate the methodology that couples WEPS with GIS for scaling predictions of wind erosion and dust emissions from field to region and to compare simulated erosion

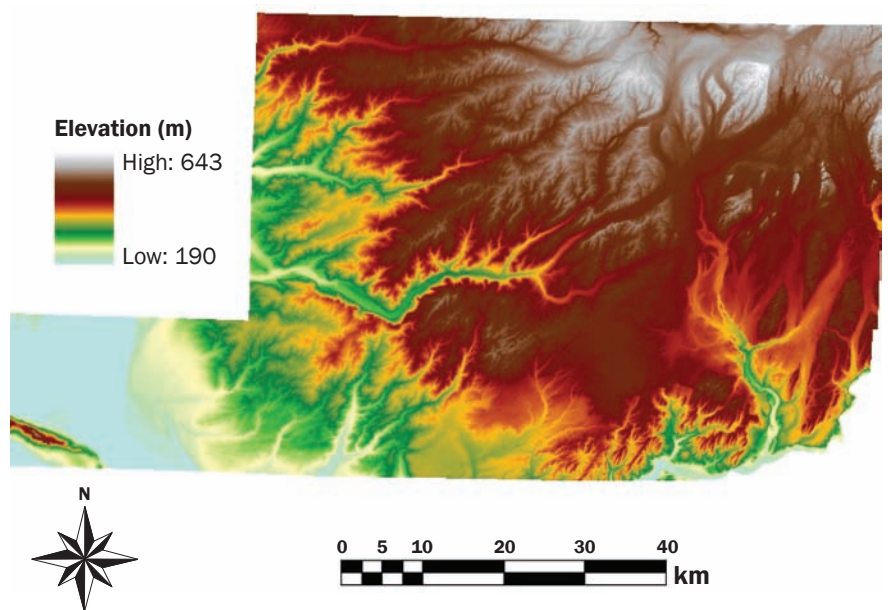
**Figure 1**

Location of Adams County and 40-year mean annual precipitation in Washington.



**Figure 2**

Elevation across Adams County, Washington.



estimates with the USDA Natural Resources Conservation Service (NRCS) classification of wind erodibility.

## Materials and Methods

**Study area.** This study was conducted using data from Adams County located in the southeastern region of Washington (47°38'N,

119°38'W) (figure 1). Soils across the county are extremely erodible and within a high conservation priority area (Chandler et al. 2004). Adams County comprises 4,986 km<sup>2</sup> (1,925 mi<sup>2</sup>) with elevations ranging from 190 to 643 m (623 to 2,108 ft) (figure 2) and slopes from 0 to 10%. Agriculture (i.e. crop production) is the pre-



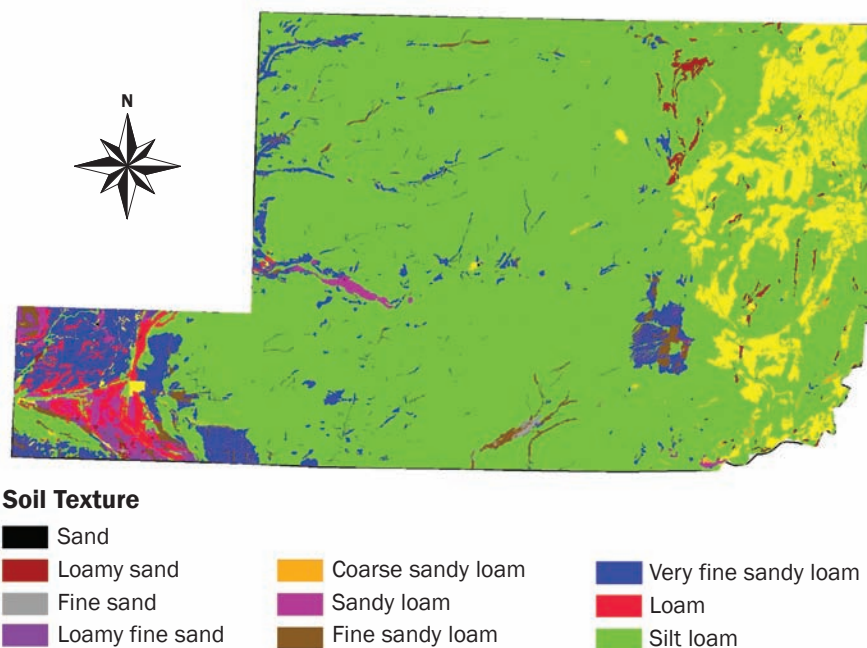
dominate industry in Adams County and winter wheat/summer fallow is the principal crop rotation employed in the county. Average annual precipitation ranges from 250 mm (10 in) on the west side to 300 mm (12 in) on the east side of the county (figure 1); precipitation mainly occurs during the winter. Soil texture across the county ranges from sand to silt loam, but 90% of the county is silt loam (figure 3). The soils are fine, fragile and very susceptible to being blown.

**Databases.** Various databases were utilized to create GIS layers of climate, soil, and land use characteristics for Adams County. State and county boundaries were obtained from the National Atlas database (<http://nationalatlas.gov/natlas/NatlasStart.asp>) for the purpose of establishing the domain of Adams County. Forty year average annual precipitation data were obtained from the Oregon Climate Service at Oregon State University (<http://nationalatlas.gov/natlas/NatlasStart.asp>) to create a map of precipitation for Washington. The United States Geological Survey (USGS) Digital Elevation Model data with a resolution of 10 m (33 ft) (<http://seamless.usgs.gov>) was used to create a map of elevation and slope and the USDA National SSURGO database (<http://nasis.nrcs.usda.gov/downloads/home.shtml>) was used to provide soil chemical, physical and hydraulic properties required by WEPS. The SSURGO database of Adams County provides a resolution of 1:20,000, therefore the minimum area represented on the soils layer was about 2 ha (4.94 ac). The spatial distribution of soil polygons along with their corresponding properties and estimated loss of soil and PM10 were displayed using GIS map format.

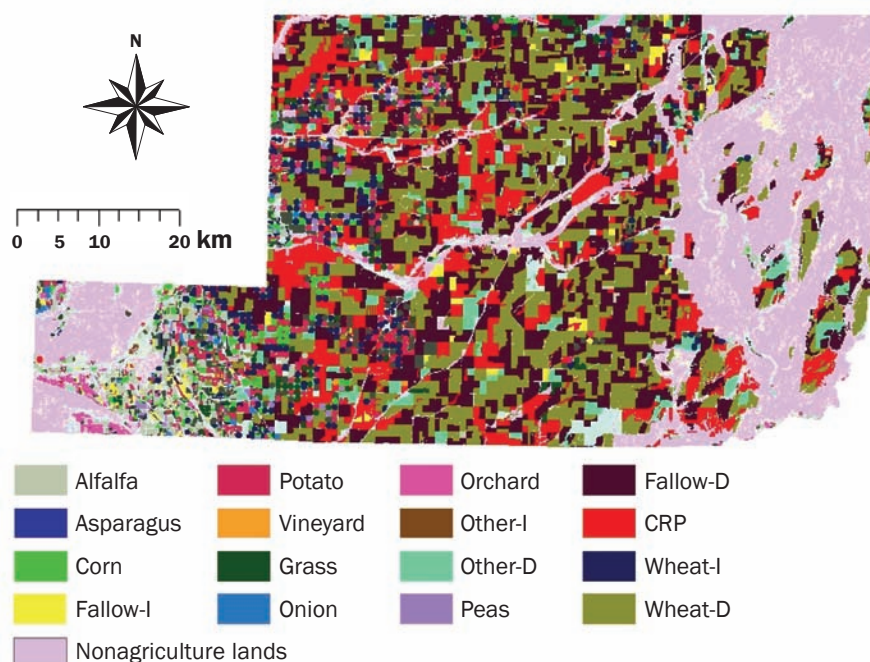
The USGS National Land Cover Database (<http://landcover.usgs.gov/natl/landcover.php>), with 232 classes of land cover and a pixel resolution of 30 m (98 ft), was used to create a land use layer in 2000 and 2001. A mask of the county was superimposed on the land cover layer for creating the land-use database for the county. Land in irrigated crops, nonirrigated crops, and summer fallow (figure 4) were spatially identified in the county. Potential loss of soil and PM10 from land in crops and summer fallow was assessed using WEPS.

The land use layer was overlain by a layer of soil polygons, along with their properties, to generate parameter values for WEPS applicable for land in crops and summer

**Figure 3**  
 Soil texture across Adams County, Washington.



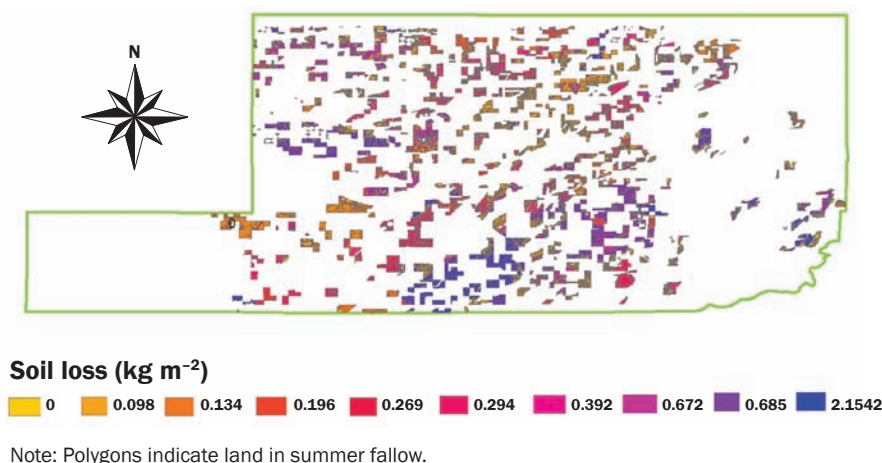
**Figure 4**  
 Land use across Adams County, Washington, in 2001.



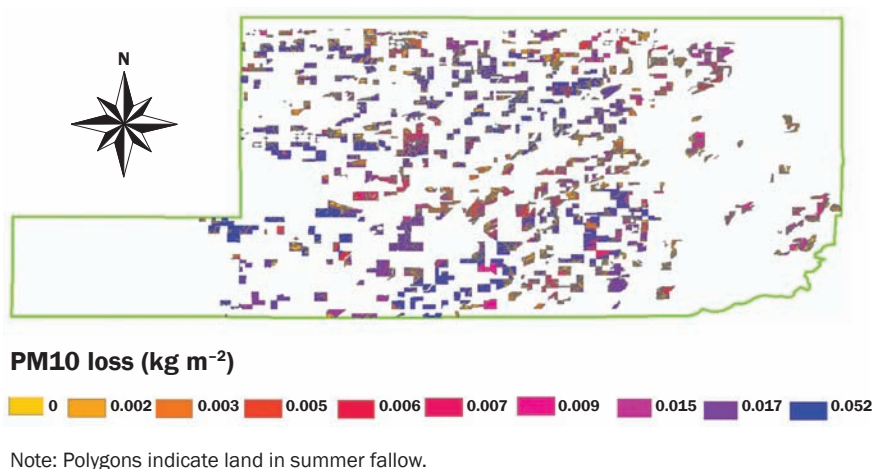
Notes: Land use designations are as follows: "Other" refers to land in crops other than those specified, CRP is land enrolled in the USDA Conservation Reserve Program, I is irrigated land, and D is rainfed or dry land.

**Figure 5**

Soil loss from land in summer fallow in Adams County, Washington.

**Figure 6**

PM10 loss from land in summer fallow in Adams County, Washington.



fallow. Information on management practices used in a wheat-fallow rotation in the county was obtained from Schillinger et al. (2004a). Information on management practices used on other crop lands was obtained from both the USDA NRCS State Agronomist for Washington and Revised Universal Soil Loss Equation, Version 2 (RUSLE2) management database applicable to crop management zone 49 ([http://fargo.nserl.purdue.edu/rusle2\\_dataweb](http://fargo.nserl.purdue.edu/rusle2_dataweb)). Weather data were simulated using WEPS based on long-term climate data obtained from Lind in central Adams County and Moses Lake in eastern Grant County. Erosion predictions by WEPS for each soil polygon were made based on the polygon's corresponding

weather, soil, and land management data. The soil polygon is the minimum simulation unit; a field includes one or more soil polygons. The area of each polygon and field was calculated by ArcGIS.

The WEPS 1.0 beta version (16a release) used in this study estimates soil loss by wind from a homogeneous, rectangular area. Erosion estimates by WEPS were compared to the wind erodibility groups (WEGs) provided in the SSURGO database.

### Results and Discussion

The land-use database indicated that 28% and 30% of land in Adams County in 2000 and 30% and 28% of land in Adams County in 2001 was respectively in winter wheat and

summer fallow (figure 4). Irrigated crops, such as alfalfa, asparagus, corn, potato, and grapes, accounted for 18% of land use in the county. Winter wheat/summer fallow is the most economically viable crop rotation for the county (Schillinger and Young 2004b); this rotation, however, is a major source of blowing dust that impairs air quality in the region. A recent study indicated that total soil loss from a fallow field in response to singular high wind events occurring over two years in the county ranged from 40 to 2,320  $\text{kg ha}^{-1}$  (0.02 to 1.04 tons  $\text{ac}^{-1}$ ) while PM10 loss ranged from 5 to 210  $\text{kg ha}^{-1}$  (0.002 to 0.095 tons  $\text{ac}^{-1}$ ) (Sharratt et al. 2006). Due to the potential for wind erosion, the land-use database indicated that 21% of the land in Adams County is enrolled in the USDA Conservation Reserve Program (CRP).

Although loss of top soil and PM10 from isolated fields maintained in summer fallow have been assessed within the county, regional inventories of soil erosion by wind from land in crops and summer fallow have not yet been established on a countywide basis due to lack of state-of-the-art tools. WEPS was used to assess erosion from land in crops and summer fallow in Adams County in 2000 and 2001. Across the county, WEPS predicted an annual loss of topsoil of 14,250  $\text{kg ha}^{-1}$  (6.4 tons  $\text{ac}^{-1}$ ) and loss of PM10 of 390  $\text{kg ha}^{-1}$  (0.2 tons  $\text{ac}^{-1}$ ) from land in summer fallow. Figure 5 indicates high soil loss from land in summer fallow in the south central and west central part of the county, and these data agree with results from a study conducted by Chandler et al. (2004) using other approaches. Areas of high PM10 emissions from land in summer fallow (figure 6) correspond with areas of high erosion. High PM10 emissions, however, also occurred from areas with little erosion (e.g. southwest part of the county). Spatial variability in soil loss and PM10 emissions did not appear to be related to differences in precipitation, topography, or soil types across the county. Soil texture across the county is predominately (90% of land) silt loam (figure 3) that contains 1.6 to 3.9% PM10; PM10 content is lower in the west and higher in the east part of the county (Chandler et al. 2004). The potential PM10 emissions hazard map created by Chandler et al. (2004) showed little trend across the county.

Based upon annual soil loss from crop land and land in summer fallow (figure 7), Adams County could be categorized into



three soil erodibility classes. The highest annual erosion rate, 10,000 to 12,000 kg ha<sup>-1</sup> (4.5 to 5.4 tons ac<sup>-1</sup>), occurred in the central part of the county, the second highest rate of 7,500 to 10,000 kg ha<sup>-1</sup> (3.4 to 4.5 tons ac<sup>-1</sup>) was in the western part of the county, and the lowest erosion rate of less than 100 kg ha<sup>-1</sup> (0.05 tons ac<sup>-1</sup>) was in the south-western and eastern part of the county. Aridisols and Mollisols comprised 90% of soil orders within county (figure 8). Wind erosion was more severe for Mollisols than Aridisols. Predominate soil types across Adams County included Ritzville silt loam, a Mollisol that constituted 27% of the land in Adams County, and Shano silt loam, an Aridisol that constituted 26% of the land in the county. Because Ritzville silt loam contains more silt than Shano silt loam (Stetler and Saxton 1996), simulated erosion was greater for Ritzville silt loam than for Shano silt loam. Annual soil loss from Ritzville silt loam was 10,500 kg ha<sup>-1</sup> (4.7 tons ac<sup>-1</sup>) whereas soil loss from Shano silt loam was 9,650 kg ha<sup>-1</sup> (4.3 tons ac<sup>-1</sup>). The low erosion rate in the southwest part of the county may result from the higher proportion of irrigated land in this part of the county; in the east part of the county, low soil loss may be due to the preponderance of range lands and basalt outcroppings (figure 4).

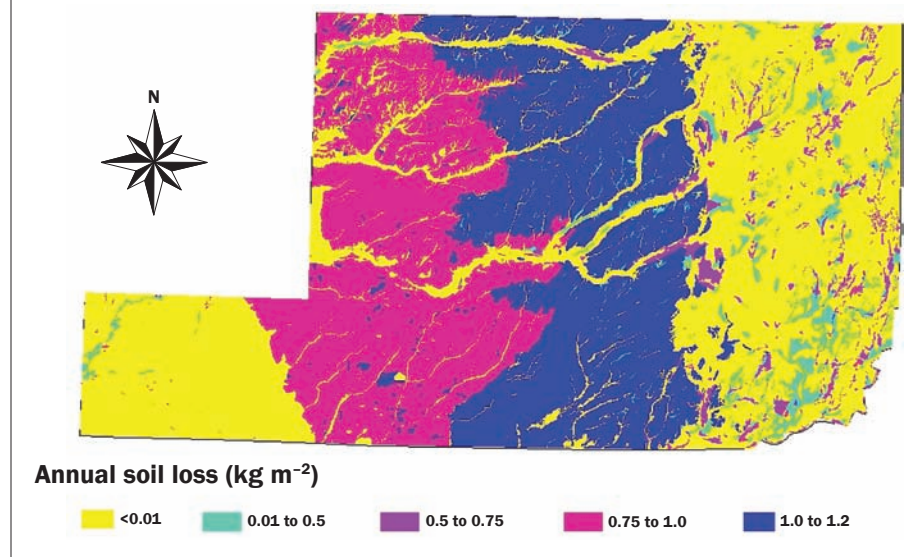
Soil type can significantly affect soil erosion, which is exemplified for a 7.3 km<sup>2</sup> (1.8 ac) area located in central Adams County (figure 9). Soil properties and field surface conditions associated with the different soil polygons could greatly affect soil erosion. In this study, soil loss assessed for various soil types mapped across the county was suppressed by an increase in surface soil water content, wilting point water content, soil aggregate stability, and soil crust stability (figure 10). Similar relationships were found between loss of PM10 and these soil properties (data not shown). These relationships can aid in guiding the development of management strategies for controlling or minimizing soil erosion. For example, strategies that promote water retention or aggregate stability will reduce erosion.

WEQ has been used to estimate average annual soil loss and is based upon the following factors:

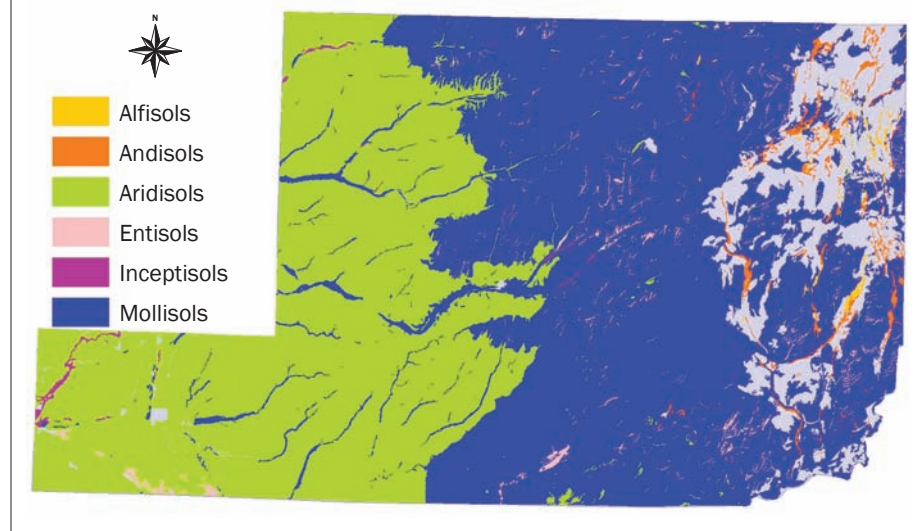
$$E = f(I, K, C, L, V),$$

where  $E$  is the estimated average annual soil loss,  $I$  is the soil erodibility index,  $K$  is the

**Figure 7**  
Annual soil loss across Adams County, Washington.



**Figure 8**  
Soil taxonomic orders across Adams County, Washington.



ridge and random roughness factor,  $C$  is the climatic factor,  $L$  is the unsheltered median travel distance of the wind across a field, and  $V$  is the equivalent vegetative cover. The soil erodibility index  $I$  is the potential annual soil loss induced by wind for an isolated, unsheltered, wide, bare, smooth, level, loose, and noncrusted field with a climatic factor equal to 100 (Lyles et al. 1983). The soil erodibility index is based solely on the relationship of potential soil erosion to the percentage of dry surface soil aggregates larger than 0.84 mm (0.03 in) determined by dry sieving.

For convenience, the USDA NRCS uses WEGs, based primarily on surface layer soil texture, as a guide for specifying the soil erodibility index factor. A WEG is defined by the USDA NRCS as a grouping of soils that have a similar susceptibility or resistance to being blown. Thus, soils within a WEG are characterized by a similar potential for soil erosion or Wind Erodibility Index (WEI). The WEI ranges from 0 tons ac<sup>-1</sup> yr<sup>-1</sup> for soils within WEG8 to 310 tons ac<sup>-1</sup> yr<sup>-1</sup> for soils within WEG1. The USDA SSURGO database contains both WEG and soil erod-

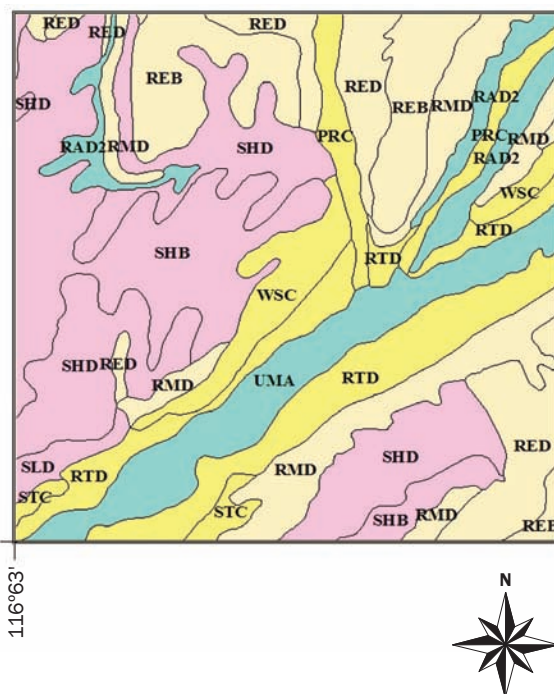
**Figure 9**

Annual soil loss from different soil types within a 7.3 km<sup>2</sup> area of central Adams County, Washington.

PRC: Roloff silt loam  
RAD2: Ritzcal silt loam  
REB: Ritzville silt loam  
RED: Ritzville silt loam  
RMD: Ritzville silt loam  
RTD: Roloff-Starbuck very rocky silt loam  
SHB: Shano silt loam  
SHD: Shano silt loam  
SLD: Shano silt loam  
STC: Starbuck silt loam  
UMA: Umapine silt loam  
WSC: Willis silt loam

#### Annual soil loss (kg m<sup>-2</sup>)

<0.01  
0.01 to 0.94  
0.95 to 1.49  
1.50 to 2.02  
2.03 to 2.40

**Table 1**

Annual soil loss for areas designated by wind erodibility groups in Adams County, Washington, as obtained from the USDA Soil Survey Geographic database and as simulated by the Wind Erosion Prediction System.

WEG	SSURGO data		WEPS simulation	
	Area	Annual soil loss (kg m <sup>-2</sup> )	Annual soil loss (kg m <sup>-2</sup> )	Annual PM10 loss (kg m <sup>-2</sup> )
1	0.13%	59	1.04	0.012
2	2.15%	32	0.46	0.011
3	11.96%	20	0.37	0.008
4	67.53%	13	1.12	0.026
5	8.45%	11	0	0
6	1.34%	9	0	0

Notes: WEG = wind erodibility group, SSURGO = Soil Survey Geographic database, WEPS = wind erosion prediction system, and PM10 = particulate matter ≤ 10 μm in diameter.

ibility index factor, the latter of which is expressed as WEI. WEQ was not designed to predict PM10 emission from farmlands, therefore PM10 emissions potential data are not available in the SSURGO database. The SSURGO database of Adams County lists six WEGs with corresponding annual soil loss ranging from 90,000 to 590,000 kg ha<sup>-1</sup> (41 to 265 tons ac<sup>-1</sup>) (table 1). Our WEPS simulation indicated that annual soil loss is highest (11,000 kg ha<sup>-1</sup> [5 tons ac<sup>-1</sup>]) from soils in the

county classified as WEG4. Although soils (sands) classified as WEG1 typically have the highest soil loss in the SSURGO database, WEG4 soils (silt loams) in Adams County appeared to be the most erodible based upon our simulation. Approximately 68% of the soil in the county is classified as WEG4 (figure 11). Soils classified as WEG3 (sandy loams) comprise the second largest area (12%) in the county, but soil and PM10 loss from WEG3 soils was relatively small com-

pared with loss from WEG4 soils. The WEG4 soils may emit more PM10 than WEG3 soils as a consequence of current tillage practices in the county. Conventional summer fallow results in a highly disaggregated and non-crusted soil, thus WEG4 soils could provide a greater source of suspension-sized material and PM10 due to the higher concentration of disaggregated silt and clay particles comprising WEG4 soils than WEG3 soils. Although WEG1 soils comprise only 0.1% of the area in the county (figure 11), loss of soil and PM10 from the WEG1 soils is relatively high. Based upon WEG classification of soils in Adams County, control measures to reduce loss of soil and PM10 should target WEG1 and WEG4 soils. The lack of correspondence between soil loss associated with WEI and simulated by WEPS (table 1) may be a result of WEI being solely based on the percentage of aggregates greater than 0.84 mm (0.03 in). WEI therefore does not account for spatial or temporal differences in field conditions such as soil moisture or crusting. Fundamentally, WEPS can provide more realistic and accurate estimates of loss of soil and PM10 than WEQ.

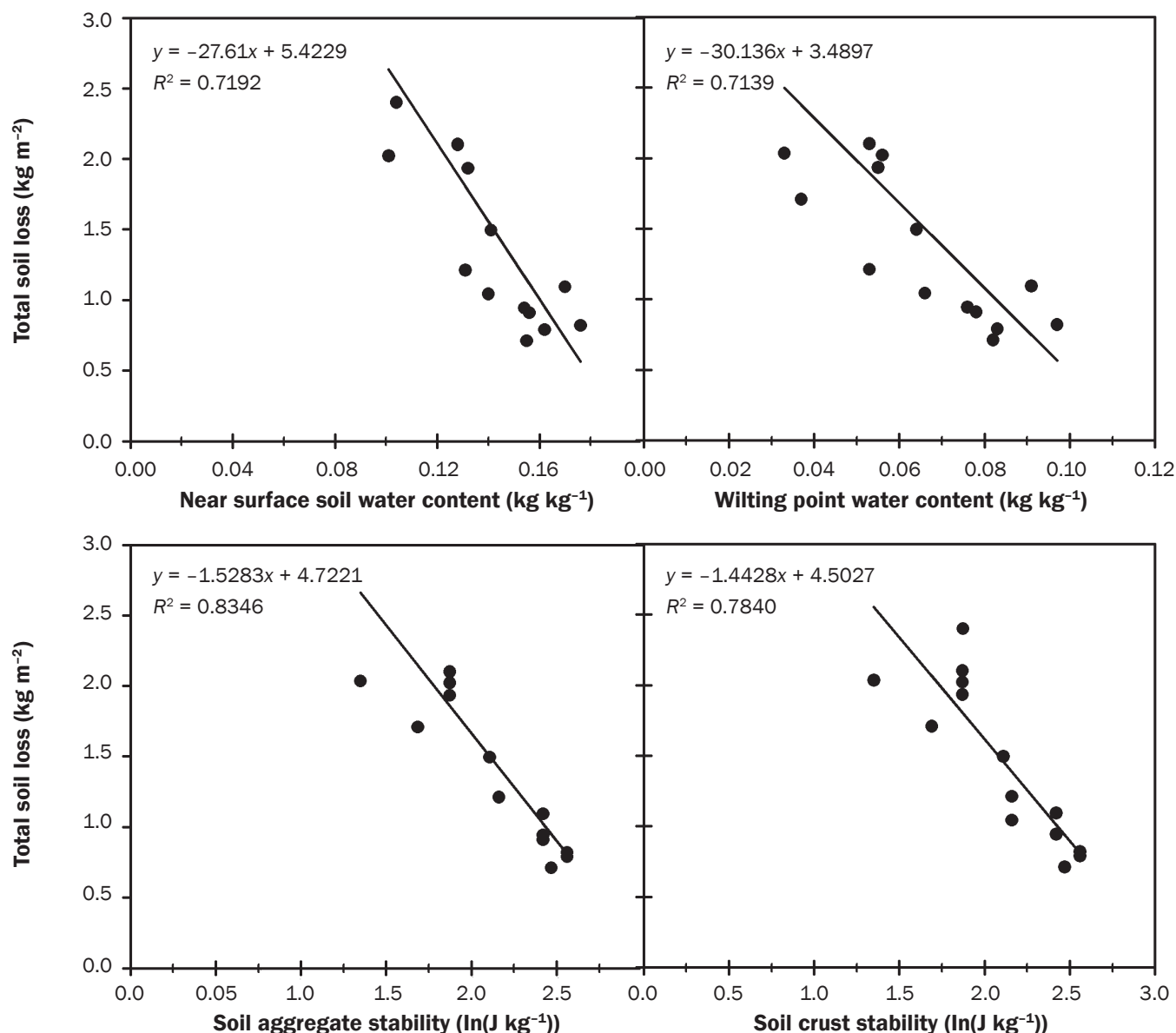
Erosion estimates based upon WEPS can be used to provide technical assistance to land managers, to inventory natural resources, to design conservation programs, and to evaluate the effectiveness of conservation practices in minimizing erosion. The methodology demonstrated in the study was effectively implemented on a county-wide basis and illustrates the possibility of simulating regional soil loss and dust emissions using GIS and WEPS.

### Summary and Conclusions

Accurate estimates of soil loss and PM10 emissions on a regional basis are essential to designing, evaluating and developing alternative cropping systems for mitigating wind erosion and improving air quality. This paper presents a methodology using WEPS and GIS to estimate and spatially characterize regional soil erosion potential. The results obtained by this method for Adams County, Washington, indicated that 14,250 kg ha<sup>-1</sup> (6.4 tons ac<sup>-1</sup>) of topsoil and 390 kg ha<sup>-1</sup> (0.2 tons ac<sup>-1</sup>) of PM10 was lost annually from land maintained in summer fallow. Soil loss and PM10 emission estimates from fields in summer fallow were spatially identified across the county. Wind erosion was more severe for Mollisols (constituting 51% of land

**Figure 10**

Relationship between annual soil loss and physical properties of various soil types in Adams County, Washington.



in the county) than from Aridisols (38% of the land area). Loss of soil and PM<sub>10</sub> were accentuated by a reduction in water holding capacity, wilting point water content, surface soil water content, soil crust stability, and aggregate stability. WEG values associated with soils in the USDA SSURGO database did not correspond to wind erosion estimates obtained with WEPS. Wind erosion estimates were highest for soils with WEG1 and WEG4 values, thus control measures to reduce loss of soil and PM<sub>10</sub> should target WEG1 and WEG4 soils in the county. The procedures that were developed in this study

and the example that was demonstrated for the regional application of WEPS in Adams County are applicable to any county or region throughout the United States.

#### Acknowledgements

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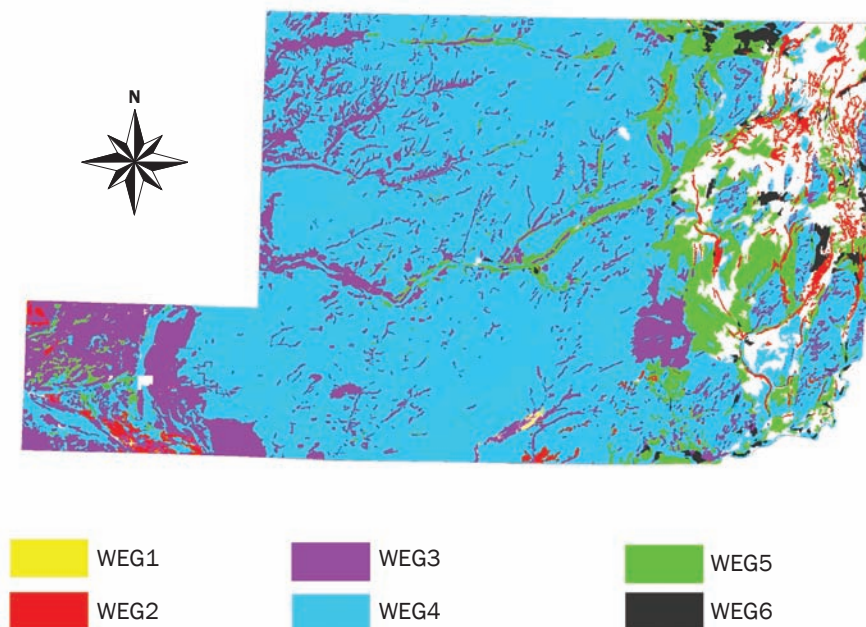
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**Figure 11**

Delineation of wind erodibility groups across Adams County, Washington.



Note: WEG = wind erodibility group.

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